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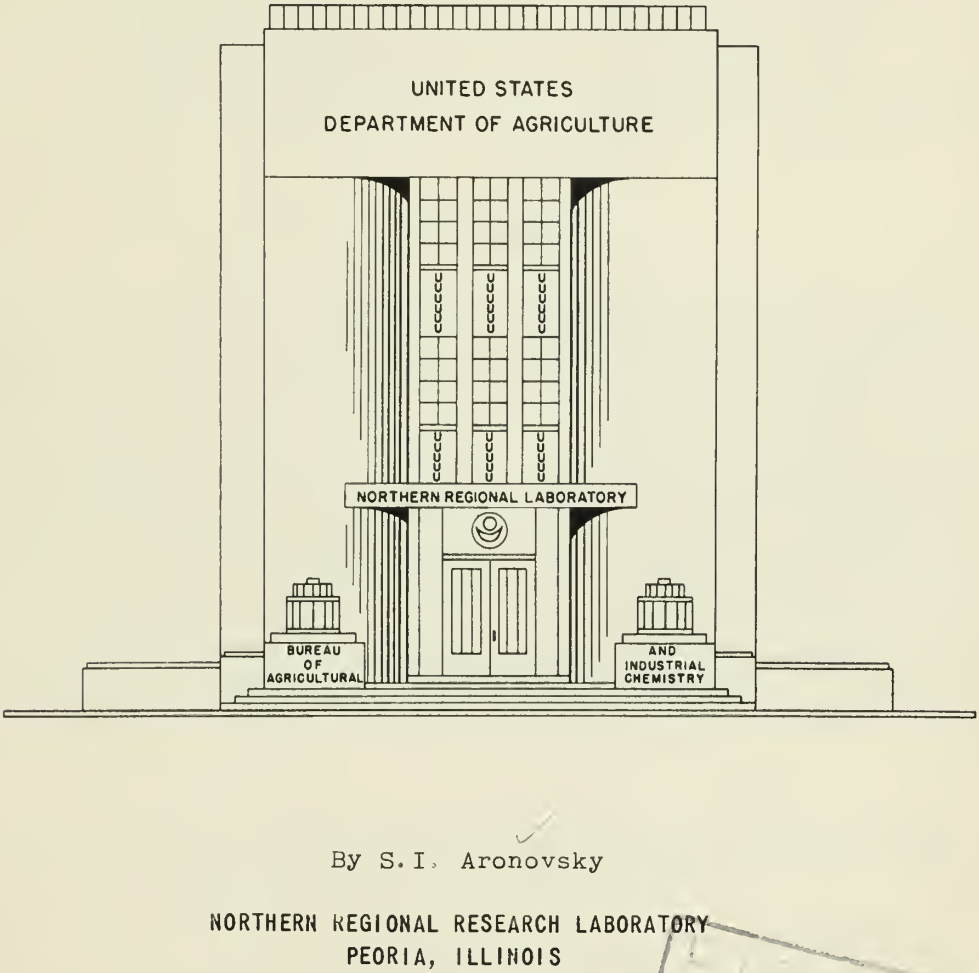
UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Administration
Bureau of Agricultural and Industrial Chemistry

RECENT ADVANCES IN PULPING STRAW IN THE UNITED STATES



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DECEMBER 1951

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CONTENTS

	Page		Page
Introduction	1	Fine paper pulp	6
Early history	2	Neutral sulfite process . .	8
Situation in 1940	4	Fine mechano-chemical straw pulp.	8
Corrugating strawboard . .	5	Straw pulp-wood pulp blends	10
Mechano-chemical process .	5	Recapitulation	10
Commercial trials	6		

INTRODUCTION

In order to evaluate the progress of straw pulping in the United States in recent years, it is desirable to describe the technological and economic conditions which prevailed prior to these newer developments. A brief historical resumé is given of the use of straw by the American paper and board industries up to about 1940 when definite changes in straw procurement practices and in the technology of the production of straw pulp began. The improvement of these conditions, aided by the work of the Northern Regional Research Laboratory whose program on the industrial utilization of agricultural residues was established at about the same time, is discussed. In addition to its work on improving the quality of strawboard pulp, the Northern Regional Laboratory has also carried on research on the development of pulps from straw and other agricultural residues suitable for the better grades of unbleached and for fine bleached papers and boards. The newer pulping processes resulting from this work have been instrumental in creating the present high degree of interest of the American pulp and paper industry in the use of straw as a supplemental raw material.

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[1] Presented at the International Pulp and Paper Symposium under the auspices of the Wood Chemistry Subcommittee of the Food and Agriculture Organization, at the Institute of Paper Chemistry, Appleton, Wisconsin, September 17-21, 1951.

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EARLY HISTORY

The cereal grain straws were probably the first raw plant material to be pulped directly for the manufacture of paper and board in the United States. The straw pulps produced were blended with rags and other waste fibers to manufacture many different grades of paper and boards to supply the requirements of this growing country. The first process developed in the United States for pulping the whole straw was patented by William MacGaw, Meadville, Penn., May 22, 1828, but a commercial trial of this process in New York State was not successful. The first successful production of a paper product from straw took place at the George A. Shyrock mill, Chambersburg, Penn., in 1831. This mill manufactured binder board on a cylinder machine, with a production capacity of 100 pounds per hour. The first pulp mill to produce a bleached straw product was erected at Rensselaer, N.Y. by John B. Davis, who reportedly used the first steam heated dryers.

Bleached straw pulp was used for newsprint and higher-grade papers. Unbleached straw paper was widely used for wrapping meats and was not displaced as butcher paper until the early part of this century. For the stronger types of paper the straw pulps were mixed with pulps made from rags, rope, or bagging. The straw wrapping paper was the forerunner of the paper bag; the stiff paper was formed into a cone which was closed, after filling, by folding over the top edges.

Straw, rags, and the other available waste fibrous products continued to be the raw materials for paper manufacture in the United States until about 1863, when the first wood pulp process was installed. The rapid expansion of wood pulp production, first by the mechanical and soda processes, then by the sulfite process, and finally by the sulfate or kraft process, supplanted the use of straw for practically all types of paper except corrugating paper. This development of new pulping processes and change in raw materials brought about a revolution in the technology and economics of paper and board making.

Low-cost groundwood pulp was found to be especially suited for newsprint and cheap magazine and tablet paper, resulting in greatly expanded publication of newspapers and periodicals. The longer fibers of chemical pulps from coniferous woods produced good writing and book paper as well as lightweight and strong wrapping paper. These coniferous wood pulps supplanted to a very large extent the relatively crude straw pulp and the expensive rags, which were generally in short supply. New paper mills were built on streams which could produce water power and, later, electric power for grinding wood and for operating machinery. Pulpwood logs were floated down the streams from the forest to the paper mills. Wood was plentiful, denser than bulky straw, easier to collect, and less costly to transport. As a result , practically the whole technology of papermaking developed in the past 80 years has been built around the use of wood although straw pulp and, to a smaller extent, rag pulp, are still used to produce specialty papers and paper products.

The main use of straw by the United States paper industry at the present time is for the production of corrugating paper for boxboard and shipping containers. The first corrugated paper was invented in 1871 by Albert L. Jones. In 1874 Oliver Long developed a method of lining corrugated straw paper with a flat sheet of paper on one side. This single-faced corrugated paper found instant popularity for packing glassware such as lamp chimneys, bottled goods, and the like. Double-faced corrugated strawboard was used about 1890 for manufacturing shipping containers and boxes. The approval for use of these containers for express shipment by the Wells Fargo Company in 1895, and for freight shipment of cereals in 1903 greatly stimulated the production of strawboard for corrugating.

A considerable amount of strawboard is used for egg case fillers, chip board, setup boxes, special cartons and paper cap stock but its major use is as a corrugating medium in the manufacture of corrugated boxboard. Stiffness, smooth surfaces, and adaptability for forming corrugated flutes at high speed are the most important properties of the strawboard The fluted tips or crown are touched with sodium silicate, starch, or other adhesives and a liner is applied to one or both sides. Ordinary strawboard is light yellowish brown, 0 009 inch thick, and weighs 26 to 32 pounds per thousand square feet. The strawboard is sold on a weight basis but is resold by the box manufacturer on a square foot basis. Competition within the corrugating board industry has tended to maintain the required physical properties of the sheet and at the same time to reduce its density.

Although the methods and machines for producing board and paper from straw have kept pace, more or less, with the advances in the production of wood pulp papers, the manufacture of straw pulp has not changed much since the beginning of this century. In the earlier production of straw pulp, the straw was boiled with a solution of lye or of milk of lime. For the production of strawboard for corrugating, the manufacturers preferred milk of lime and this chemical was used almost exclusively in this industry until recent years.

The early commercial production of straw pulp for corrugating took place in open tubs. These units, about 20 feet in diameter, and about 10 feet deep were filled with alternate layers of raw straw, from the hay rack or pile, and milk of lime, and the whole was cooked with low-pressure steam for 8 to 10 hours. After sufficient time for cooling the cooked straw was forked from the tub onto conveyers and then washed, beaten, and made into paper in the paper mill. A gradual change-over from open-tub cooking to the use of globe rotary cooking took place around the turn of the century.

Lime continued to be practically the sole cooking agent for corrugating straw pulp until about 1920 when extracted chestnut chips, from which the tannin had been removed by water extraction, and kraft pulp began to produce, competitively, 9-point corrugating paper which was accepted by shippers. The outstanding advantages of lime as a pulping agent are its low cost and relative insolubility in water. Small amounts of lime produce large quantities of saturated lime water, as the lime is used up or neutralized in the pulping process more of the unused material is dissolved and a saturated solution is thus maintained until all of the lime has been absorbed by the straw or converted to other products. Cooking with lime, therefore, required no particular controls, as long as there was sufficient chemical present to do the required job of pulping. Also more uniform pulping conditions could be maintained with lime than with similar small amounts of the other conventional cooking chemicals, which would tend to be absorbed by a small portion of the straw, leaving the remainder of the straw partly or completely unattacked by the chemical.

The disadvantages in the use of lime for pulping are that lime and its salts are difficult to remove from the cooked straw in the usual washing cycle, resulting in an alkaline reacting pulp The lime salts gradually fill up the wires and the felts of the paper machinery resulting in frequent shutdowns and consequently lower production. Also the frequent washing or "souring" of the wires and felts with acid shortens the life of the clothing considerably.

The advent of chestnut and kraft pulp into the corrugating field caused the strawboard industry to look into ways and means of improving the quality of their product. A number of these strawboard mills began investigating the possibilities of using soda salts and sulfur in addition to lime for pulping the straw. Many such chemicals were tried, including caustic soda, soda ash, sodium sulfite, and sodium sulfide, and, in a number of cases, elemental sulfur was added to the rotary charge.

Strawboard made from straw cooked with only lime carries over a peculiar odor. It was found that eggs held in cold storage in cases with a lime-cooked strawboard filler acquired an unpleasant musty taste which could not be attributed to the eggs, and was ascribed to contact of the eggs with the strawboard and absorption of its undesirable odorous constitutents. This particular strawboard odor can be reduced or eliminated by pulping the straw with sodium sulfite or with soda ash and sulfur. The use of these added chemicals resulted in improving the quality of the strawboard corrugating paper, but the chestnut and kraft pulps continued to make inroads into this field.

Briefly, the operations for manufacturing strawboard for corrugating are as follows: Baled straw from the mill rick or from a truck is conveyed into the digester house. The bale wires are cut and removed and the partially broken bales are loaded into 14-foot spherical rotary digesters with a capacity of about 6 tons of air-dry straw. The total chemical charge varies from 5 to 9 percent, basis air-dry straw, and the water charge is 500 to 625 gallons per ton of straw. The straw charge itself varies from 3 to 6 tons depending on the number of fills used, for instance, 1 to 4. The cooking pressure is 5 to 60 p.s.i. and the cooking time at maximum pressure varies from 3 to 13 hours. The cooked straw is dumped onto chain conveyors which carry it to seasoning pits or to washers. The old practice of draining and seasoning the hot, lime-cooked straw for 48 to 60 hours before sending it to the beaters is still practiced in some mills. The cooked straw is beaten for 2 to 3 hours at 4 to 7 percent consistency, with simultaneous washing by means of washing drums to remove the cooking chemical, very fine fiber, and debris from the pulp. Other defibering and refining equipment such as rod and disc mills are used by some plants. The beaten stock is passed through two or more jordans and then generally screened before it is formed into a sheet on the paper machine. The latter is generally a cylinder machine but some mills use Fourdriniers. The formed sheet is pressed, dried, lightly calendered, reeled, and slit and rewound to the customer's specifications, as in the manufacture of other papers. In spite of all the variations enumerated above in the different mills, a check test run in 1947 on the strawboard produced by these mills showed that the corrugating paper manufactured by the various procedures was remarkably uniform in quality.

SITUATION IN 1940

That was the status of the corrugating strawboard industry in the United States in 1940, when the Northern Regional Research Laboratory of the United States Department of Agriculture was organized and started work on the utilization of straw and other agricultural residues for the production of pulp, paper, and board products. This was also about the time when combine threshing of grain had largely supplanted the binder method and difficulties were encountered by the mills in straw procurement. The first efforts of the Northern Laboratory were aimed, therefore, toward helping solve this procurement problem, involving the development of specifications for baled straw and of equipment to gather and bale it. The Laboratory also helped the strawboard industry develop suitable methods of preserving the baled straw in storage in large ricks. A 400-ton rick can be suitably protected from microbial attack by dusting the top layers of straw bales with about 1 ton of crude borax.

CORRUGATING STRAWBOARD

In the meantime experimental work was carried on at the Northern Regional Research Laboratory on methods of improving the pulping of straw for corrugating. Preliminary experiments showed that cooking straw with 6 percent lime and 1.5 percent caustic soda, a mathematical average of the amounts of chemical used in the commercial production of strawboard in the corrugating industry, gave a pulp which was essentially similar to that produced by the industry. With these conditions as a base for laboratory pulping, many experiments were tried with varying proportions of the different chemicals commonly used for pulping, and an empirical method of evaluating the straw pulp was developed, using a 5-pound beater with a washer attachment for defibering and washing the pulped straw. These preliminary laboratory experiments showed that caustic soda, sodium sulfite, or a combination of the latter with caustic soda or with soda ash, with elimination of all or most of the lime, gave pulps with considerably higher Riehle crush resistance than could be obtained by cooking with lime alone or with large proportions of lime in the formula.

With the greatly increased production and improved quality of corrugating wood pulps, particularly the semi-chemical hardwood pulps, the Northern Laboratory concentrated more directly, with active cooperation of the strawboard industry, on developing improved pulping methods for straw. Four men from three strawboard mills participated actively in this work. Four new pulping formulas were developed, each capable of producing a superior corrugating straw pulp. It was considered desirable to develop more than one type of formula so that each of the strawboard mills, with its different equipment and methods of operation, could use the formula which came closest to its own conditions. These chemical formulas were 6 percent caustic soda, 10 percent sodium sulfite, 2 percent caustic soda plus 4 percent sodium sulfite, and 2 percent sodium sulfite plus 4 percent soda ash, all based on the oven-dry weight of straw (fig. 1). The pulps obtained by cooking with these chemicals were vastly superior in strength properties, particularly crush resistance, to lime-cooked straw pulp. Most of the mills in this country producing strawboard for corrugating have adapted these cooking formulas to their commercial operations, and some have produced corrugating strawboard with crush resistance superior to that of the semi-chemical hardwood corrugating paper. These results corroborate the oft-repeated claim of the Northern Laboratory that straw pulp and pulp from similar high-hemicellulose agricultural residues would make corrugating paper with crush resistance superior to that of wood and other plant materials which have lower amounts of hemicellulose.

MECHANO-CHEMICAL PROCESS

It was during this period that the new revolutionary mechano-chemical process for pulping agricultural residues was developed at the Northern Laboratory. This process involves cooking the raw material in an open vessel at atmospheric pressure and at temperatures up to 100° C. The vessel used in this development was a Hydrapulper. The rapid pulping rate was attributed to the impact action of the impeller of the Hydrapulper in forcing or "pumping" the chemical liquor into and out of the straw or other agricultural residue material. This process is not limited to the use of the Hydrapulper since other equipment which produces similar impact action has

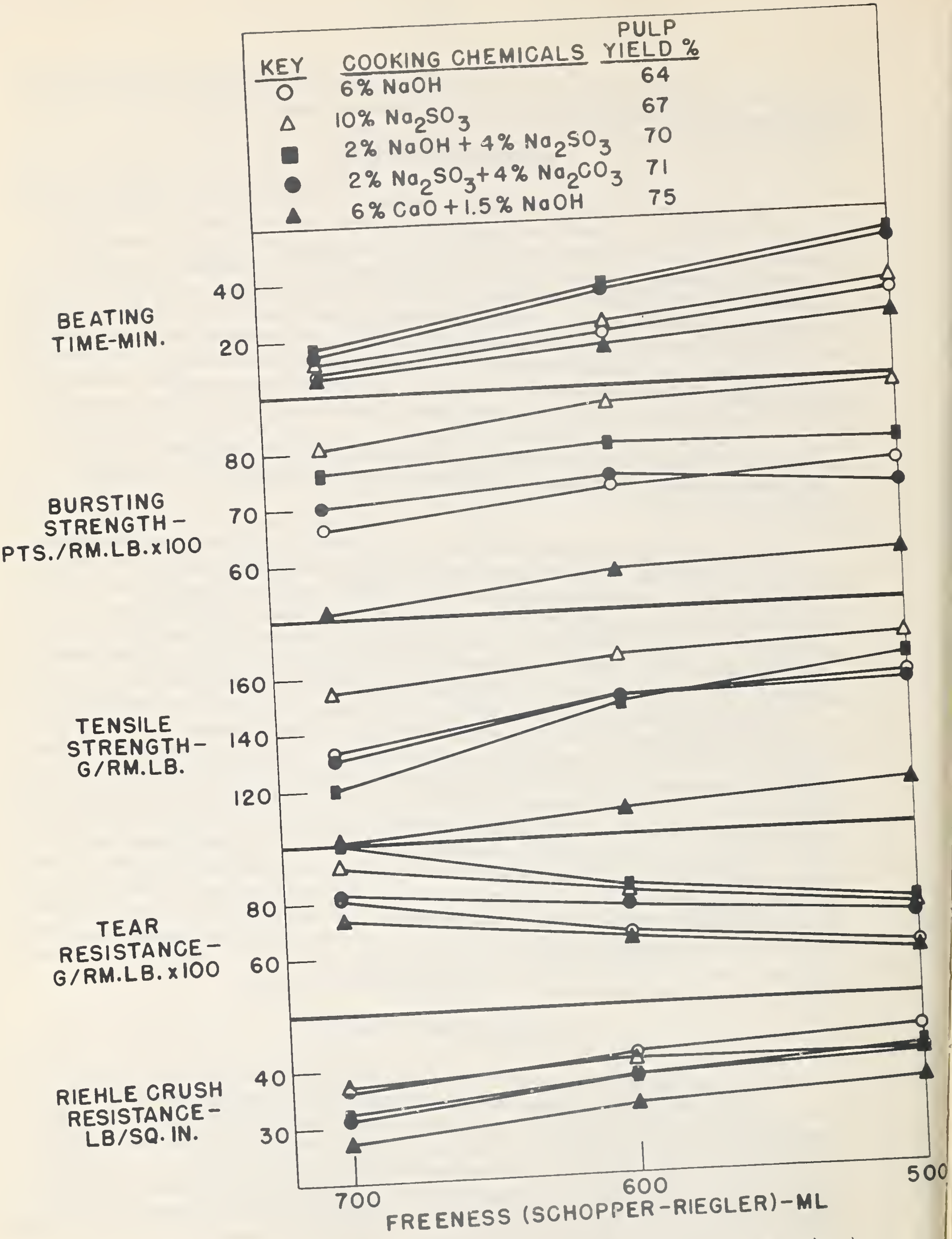

Figure 1.--Yields and properties of corrugating straw pulps produced with sodium compounds as compared with regular lime-cooked pulp.

given equally good results. The main requirement of the equipment is that it circulate straw and chemical at a sufficiently high rate so that a good vortex is developed and maintained in the unit, resulting in rapidly repeated impacts of the straw particles by the impeller vanes. This result was obtained in a commercial Hydrapulper by using a larger rotor or impeller than is required for defibering dried pulp or waste paper.

Straw cooked in a 3-foot Hydrapulper for 1 hour at 98° C., with 6 percent lime and 1.5 percent caustic soda, gave a pulp which was fully equal in yield and strength characteristics to that produced by cooking with the same amount of chemical for 5 hours at 140° C. (40 p.s.i.). The ratio of total liquid to straw at the beginning of the cook was 9:1 and the final consistency at the time of discharge was about 6.5 percent due to solution of some of the straw constituents and dilution with the cooking steam. With caustic soda the mechano-chemical process produced a corrugating pulp in high yield, and with properties similar to those of pulp produced by cooking straw with the same amount of caustic under the usual pressure cooking conditions.

COMMERCIAL TRIALS

Commercial-trial pulping of straw in an 11-foot Hydrapulper corroborated the results obtained with the smaller laboratory unit. As a matter of fact, the larger equipment seemed to do a better and faster job of pulping. Straw was cooked with lime and soda ash, lime and caustic soda, and with caustic soda alone, using the same total amount of chemical as required for pressure cooking in the standard 14-foot rotaries. The wire was removed from the bales at the Hydrapulper and these bales were then dumped whole into the hot liquor in the unit. The starting straw consistency was 10 percent. After cooking for 1 hour the pulped straw was discharged by gravity flow through a 16-inch line in a matter of 2 or 3 minutes. The complete time cycle for filling, cooking, and discharging was not more than 90 minutes. The pulp so produced was fully equal in strength characteristics to that made by cooking with the same amount of chemical for 5 to 6 hours at 50 pounds pressure in the globe rotary. No particular difficulties were encountered in producing corrugating paper from this pulp on a commercial cylinder paper machine. The corrugating paper was similar in all respects to that produced by the regular production methods at this particular mill.

In another mill trial wheat straw and sugarcane bagasse were pulped in a 3-foot Hydrapulper with caustic soda. The cooked materials were defibered in a Bauer refiner and run over a small experimental Fourdrinier paper machine to produce 9-point corrugating paper. This paper was then corrugated on a large commercial machine and attached to a single liner. The resulting single-faced corrugated board had considerably higher flat crush strength than boards made from bogus corrugating or from cold caustic semi-chemical mixed hardwood pulps produced on the same paper machine.

The main advantages of mechano-chemical processing lie in lower labor and steam requirements, a saving in space, and simplicity of operation and control. This process is capable of push-button, streamline operation. Mill insurance rates in operation of this process can be lower because no pressure equipment is involved.

FINE PAPER PULP

As indicated previously, there is at present no commercial production of fine or bleached pulp from cereal grain straw, bagasse, or similar agricultural residues in this country. Bleached fine pulp from straw was used in blends with wood and rag pulps for various grades of paper, including newsprint, up to the first decade of this century. Since that time straw has been used for the production of only the coarser grades of paper and for paper board, leaving the field of fine paper almost entirely to wood and rag pulps. A fair tonnage of tow from seed flax straw is used in the production of cigarette, condenser, and similar high-grade papers. A small amount of cotton linters is being processed for use in paper manufacture. A small mill was reported producing bleached pulp from rice straw in California about 30 years ago but that mill is no longer in operation. Before World War II several hundred tons of bleached straw pulp were imported annually from Europe for use in Bristol, drawing and art papers, and for similar specialty products.

Interest in straw pulp for paper manufacture was renewed during World War II and has increased since that time due to greater demand for paper and board, lessening supplies of pulpwood and wood pulp, and greater costs of these materials. Research work on the production of fine pulp from straw was begun at the Northern Laboratory in 1940 when the program on pulp and paper was set up. It was decided early in this program that the best way to make straw pulp attractive to the paper industry was to put the manufacture and use of this material on a sound economic and practical basis. The conception of producing straw pulp merely as a substitute for other types of fibers during periods of shortage was discarded as unsound. For continued use by the paper industry, straw pulp or pulp from similar agricultural residues has to provide a property or effect which cannot be produced so easily or so well by other types of pulps. These agricultural residue pulps must be considered as supplementary rather than substitute raw materials for the industry.

A considerable amount of work has been reported in the literature on the pulping of straw and other agricultural residues, but most of this work refers to scattered or isolated experiments from institutional or pulp and paper mill laboratories. The Northern Laboratory established for the first time a broad pulp, paper, and board research program devoted entirely to the use of such agricultural residues. The pulping and pulp and paper characteristics of these residues could thus be evaluated in one place, under a unified set of conditions, and the results would therefore be fully comparative and easily understandable.

It is known that while the alpha-cellulose contents of straw, bagasse, and similar agricultural residues are lower than those of wood, the holocellulose contents of these materials are practically all alike, with the agricultural residue materials containing more hemicelluloses or pentosans than woody plant material. The first work in the Northern Laboratory program for fine pulp involved, therefore, a search for a pulping method which would give a pulp with a yield as close to the holocellulose value as possible. After experimenting with a large number of pulping agents, organic as well as inorganic, it was found that the most practical method of producing a high yield of suitable pulp from straw was to cook the material by the neutral sulfite method. Comparable pulping studies on wheat straw were also made with the soda, kraft, acid sulfite, and ammonia processes. The acid sulfite and ammonia pulps were quite weak. Good quality pulps were obtained by the soda and kraft processes but the pulp yields were considerably lower than those produced with the neutral sulfite method.

NEUTRAL SULFITE PROCESS

The optimum condition for pulping soft winter wheat straw for example, was 8 percent sodium sulfite and 3 percent sodium carbonate, based on oven-dry straw, 2 hours' cooking at a maximum temperature of 170° C. (100 p.s.i.), and a liquor to straw ratio of 7:1. At the start of cooking, the temperature was brought up to maximum as rapidly as possible, usually 15 to 20 minutes, and at the end the pressure was lowered as rapidly as possible, without excessive loss of liquor, to about 40 p.s.i. The charge was then blown into a blowpit. Afterwards it was washed, screened on an 8-cut flat plate, and bleached. The average yields, based on oven-dry straw, obtained in this operation were: crude pulp, 62 percent; screened pulp, 54 percent; screenings, 2 percent; and fines, 6 percent. Discharging the digester contents under pressure almost completely eliminated, more or less, the difficulties with slow stock encountered in European and South American practices of producing straw pulp. Upon blowing, the nodes and rachises, or heads, exploded into their constituent tiny fibers, platelets, and cells which could be screened out by deckering, or by an additional screening step. The screened neutral sulfite pulps have unbeaten freeness values of 800 to 820 ml. Schopper-Riegler which is a fairly high freeness for short-fibered pulp. This pulp requires about 5 percent total chlorine to bleach to a brightness of 70, in a three-stage operation; about 7 to 8 percent chlorine produces a brightness of about 80. The yield of bleached pulp, based on original dry straw, varies from 47 to 50 percent, depending on the brightness of the pulp attained.

A commercial trial of this process was made in a large Canadian newsprint mill under conditions which were very difficult because of the need to avoid interference with regular newsprint production. About 7 tons of screened pulp were produced, and the calculated yield was about 52 percent, based on original straw. This pulp was bleached and incorporated into the regular commercial newsprint paper, forming 17 to 20 percent of the total furnish. This furnish was run on a 183-inch paper machine at 1120 feet per minute, and no breaks were encountered during the entire run of about 6 hours, with a production of approximately 35 tons of paper. This paper, printed on the presses of a large American daily, produced 163,000 copies of a 28-page newspaper, again without a break which could be attributed to the paper. The straw-containing commercial newsprint paper had somewhat smoother surfaces, and the formation was somewhat better than that obtained in the regular all-wood sheet. This process is now being used, with more or less modification, for the commercial production of straw pulp in a number of European countries.

FINE MECHANO-CHEMICAL STRAW PULP

The mechano-chemical process for producing fine pulp from straw and similar raw materials at atmospheric pressure was announced by the Northern Laboratory in February 1949. An excellent pulp can be produced from straw by cooking the latter in a Hydrapulper for 1/2 hour at 98° C. with 10 to 12 percent caustic soda or kraft chemicals, based on dry straw. This process is not efficient for use with sodium sulfite which requires higher temperatures for practical pulping.

The screened (8-cut) mechano-chemical pulp is fully equal in strength properties to that obtained by cooking with the same amount of chemical for 2 hours at 170° C. (100 p.s.i.), but the yield of mechano-chemical screened pulp is 53 to 55 percent as compared with 45 to 47 percent obtained by the pressure cooking method (table 1). This mechano-chemical process also produces relatively free pulp, with an unbeaten Schopper-Riegler freeness of 750 to 800 ml.

TABLE 1.--*Comparison of wheat straw pulps produced by various processes*

Item	Process				
		Kraft		Soda	
	Neutral sulfite	Mechano-chemical	Pressure	Mechano-chemical	Pressure
		Percent yields[1]			
Crude pulp	62	63	53	62	52
Screened pulp	54	55	47	53	42
Screenings	2	4[2]	1	5[2]	3
Fines	6	4	5	4	7
		Constituents in screened pulp, in percent			
Ash	7.9	1.9	4.9	1.3	4.7
Lignin	5.4	6.1	4.0	6.6	5.3
Pentosans	29.1	32.5	30.0	34.5	23.2
		Strength at 500 ml. S-R			
Bursting[3]	96	105	99	109	104
Tensile[4]	174	194	175	184	188
Tearing[4]	53	55	46	49	55
Folding[5]	350	450	470	660	810

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[1] Basis oven-dry straw.

[2] Rifflings plus screenings.

[3] Points per ream-pound.

[4] Grams per ream-pound.

[5] Double fold (Schopper).

The nodes and rachises are eliminated in this process also, but in a different manner from that obtained in the neutral sulfite method. In mechano-chemical pulping the nodes, rachises, and seed kernels are swollen but not pulped. After cooking in the Hydrapulper, the material is washed and then sent to a riffler at a consistency of about 0.5 percent. The swollen nodes, rachises, and seeds settle out quite readily in the riffler, and only a small portion of these materials is carried over to be caught on the 8-cut flat screen. The lower fines content of the mechano-chemical straw pulp also is laid to the fact that the nodes and rachises are not broken up in the Hydrapulper. Mechano-chemical soda pulp from straw has been bleached to a brightness of 82.4 in pilot-plant operation, with a total chlorine consumption of 8.7 percent, based on original dry straw, in a 3-stage operation involving chlorine, alkaline extraction, and hypochlorite. The yield of bleached pulp was found to be 47 percent of the original weight of dry straw.

STRAW PULP--WOOD PULP BLENDS

This bleached straw pulp was blended with wood pulp in the production of various grades of paper on an experimental Fourdrinier paper machine. Control runs of all-wood pulp furnishes were made on the same machine. The straw pulp was beaten to a Schopper-Riegler freeness of 500 ml. (Canadian Standard 190 ml.) in all cases, and the wood pulps used in the blends were beaten in the same manner as for the control runs. The following papers were made using bleached sulfite or unbleached kraft wood pulps in the controls: magazine-book for coating, including groundwood in the furnish; newsprint from a furnish of blank news and sulfite in one case and blank news and straw pulp in the other; soda book, including soda wood pulp; bond; waxing; and kraft for wrapping and bag. A grease-proof or glassine sheet was also made from a furnish of 75 percent of the mechano-chemical straw pulp and 25 percent sulfite pulp which were beaten together to a freeness of 200 ml. Schopper-Riegler. The proportions of the bleached straw pulp in the furnishes of the other papers varied from 25 to 60 percent of the furnish.

In all cases better formation and smoother surfaces were obtained when straw pulp was used as part of the furnish. The paper containing straw pulp also invariably had higher mullen and tensile strength, as well as higher folding strength than the all-wood pulp paper. The tearing resistance was lower, of course, for the straw-containing paper because of the shorter fiber length of the straw pulp.

The improved formation of the paper containing straw pulp is due mainly to the very narrow diameter of the straw fiber, and consequently, to its high length-to-diameter ratio. This improved formation is confirmed by the fact that where straw pulp was added to the furnish the difference in the strength properties of the paper in its two directions was decreased, i.e., the strength in the cross direction increased to a greater extent than that in the machine direction. The smoother surfaces of the straw-containing paper are due primarily to the fact that the straw fibers in the paper surfaces were relatively unfibrillated and smooth. Straw pulp with its relatively high hemicellulose content hydrates so rapidly that the maximum strength values of the pulp are obtained before the fibers are bruised to any large extent. From a practical standpoint, this property of the straw pulp means a saving in power for beating or refining.

RECAPITULATION

With the cooperation and encouragement of the American paper and board industries, considerable advance in the utilization of straw pulp can be reported. The new pressure pulping formulas and the mechano-chemical process for strawboard pulp give promise of returning straw to its former pre-eminent position in the corrugating board industry. Similarly, the high-yield neutral sulfite process and the equally high-yield mechano-chemical process bring the production of fine paper pulp from straw into the economic range of present day competitive pulps from other raw materials. These new developments and the constantly and greatly increasing interest of the pulp and paper industry emphasize the possibilities of straw for fine pulp and paper manufacture in the United States. It appears probable that these fibrous agricultural residue pulps will attain a permanent place as raw materials in the American pulp and paper industry in the very near future.

CONCLUSION

Agricultural fibers of diverse nature are readily available in most parts of the world. Research into their physical, chemical, and papermaking properties backed up with a considerable industrial experience in their use shows that they can greatly benefit the expanding paper industry not only by increasing pulp supplies but even more important, when properly used, to produce new and improved paper and board products. Now, industry is somewhat reluctantly extending the present limited use of these fibers. The greatest challenge to industry in this period of expansion lies in a reorientation in viewpoint so that raw materials are not confined to any particular type but are sought and used on the basis of producing better, newer, and more useful paper and board products. With such a reoriented viewpoint, the very great possibilities in the use of agricultural fibers become apparent. With such a viewpoint, research and industry can proceed to solve the problems facing them with confidence.

The mention in this publication of commercial products under proprietary names does not constitute an endorsement by the U. S. Department of Agriculture.